Cerebrospinal fluid drainage and distal aortic perfusion: Reducing neurologic complications in repair of thoracoabdominal aortic aneurysm types I and II

Hazim J. Safi, MD, Kenneth R. Hess, PhD, Mark Randel, MD, Dimitrios C. Iliopoulos, MD, John C. Baldwin, MD, Ravi K. Mootha, BS, Salwa S. Shenaq, MD, Roy Sheinbaum, MD, and **Thomas Greene, MD,** *Houston, Tex.*

Purpose: This study was conducted to evaluate the role of cerebrospinal fluid (CSF) drainage and distal aortic perfusion (DAP) in the prevention of postoperative neurologic complications for high-risk patients who had undergone type I and type II thoracoabdominal aortic aneurysm (TAAA) repair.

Methods: CSF drainage and DAP were used as an adjunct in the treatment of 94 patients with TAAA (31 type I, 63 type II) between September 1992 and December 1994; 67 were men and 27 were women. The median age was 64 years (range, 28 to 88 years). Aortic dissection occurred in 35 of 94 patients (37%). Thirty-six of 94 patients (38%) had previously undergone proximal aortic surgery. All patients underwent intraoperative DAP and perioperative CSF drainage. Median aortic cross-clamp time was 67 minutes (range, 20 to 131 minutes).

Results: The 30-day survival rate was 90% (85 of 94 patients). Early neurologic complications occurred in 5 of 94 patients (5%), and late neurologic complications occurred in 3 of 94 patients (3%). We compared the neurologic complications of our current group of 94 patients with the data from 42 patients (control group) who also underwent repair of TAAA type I and type II with only simple cross-clamp and without CSF drainage or DAP. Both groups were treated by the senior author (HJS) at the same institution. Total neurologic complications for the current group occurred in 8 of 94 patients (9%) versus 8 of 42 patients (19%) for the control group ($p = 0.090$). Neurologic complications for patients with type II TAAA occurred in 8 of 63 patients (13%) versus 17 of 42 patients (41%) ($p = 0.014$). For all patients with aortic clamp times ≥ 45 minutes, neurologic complications occurred in 7 of 55 (13%) versus 7 of 18 (39%) ($p = 0.033$).

Conclusion: The period of risk during aortic cross-clamp time is reduced with the adjuncts of CSF drainage and DAP, which significantly lower the incidence of neurologic complications after repair of TAAA types I and II. (J VASC SURG 1996;23:223-9.)

TAAA surgical repair and cross-clamping of the aorta have been shown to be highly associated with the development of neurologic complications.[1,2] Other factors that have been implicated in the development of neurologic complications are aneurysm extent (Crawford types I, II, III, and IV), cause (dissection), previous aortic surgery, age, preoperative renal function, and rupture.[3-5] A multitude of methods are used in the effort to extend the tolerance of the spinal cord to aortic cross-clamping, including generalized profound hypothermia or localized hypothermia to decrease the metabolic rate of the spinal cord; medications such as steroids, naloxone, barbiturates, and papaverine; and identification of the critical artery of Adamkiewicz, both before surgery by aortography and during surgery by somatosensory or motor-evoked potentials.[6-12]

From Baylor College of Medicine, the Methodist Hospital, Houston.

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Reprint requests: Hazim J. Safi, MD, 6550 Fannin, Suite 1603, Houston, TX 77030.

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Our preliminary prospective study showed that the combination of CSF drainage and DAP can lower the neurologic complications of TAAA surgical repair.[4] The rationale for this method of spinal cord protection is that during aortic clamp time, distal aortic pressure decreases markedly and causes a decrease in spinal artery pressure and a rise in CSF pressure.[12] CSF drainage, both during and after surgery, decreases CSF pressure and augments the perfusion of the spinal cord. Left atrial to left femoral bypass, or DAP, increases distal aortic pressure and leads to an increase in the spinal artery pressure, thus increasing perfusion pressure of the spinal cord. Implementing these two methods had a salutary effect on protection of the spinal cord and reduced the incidence of neurologic complications.[13-15]

The 45 patients in our preliminary series were TAAA types I and II and are included in our current study. After the first series was completed and the benefits from CSF drainage and DAP became clear, we began to use passive hypothermia of a rectal temperature of 34° to 32° C and to maintain CSF pressure at 10 mm Hg, rather than at the previous pressure of 15 mm Hg. These changes produced no discernible alterations in neurologic complications. For the possible benefits of passive hypothermia in decreasing metabolic rates and the results of lower CSF pressure in further increasing acceptable ischemic time to the spinal cord, we will have to examine a much larger group of patients in a completely different light.

MATERIALS AND METHODS

Between February 1991 and December 1994, 227 patients underwent TAAA repair. Ninety-four of these patients who received the surgical adjuncts of CSF drainage and DAP during type I and type II thoracoabdominal aortic repair made up the study group. The control group was comprised of 42 patients who underwent type I and type II thoracoabdominal aortic repair with aortic cross-clamp alone and no adjuncts. All 53 patients who underwent repair of type III and IV TAAA were eliminated from the study. Also eliminated from the study were 38 patients who had CSF drainage or DAP but not both; two had only CSF drainage, and 36 had only DAP. Twenty-one were type I and 17 were TAAA type II. Ten patients (26%) had neurologic deficit.

CSF drainage and DAP were used as adjuncts in the surgical repair of TAAA types I and II beginning in September 1992. The study group of 94, all of whom received CSF drainage and DAP, included 67 men and 27 women. The median age was 64 years (range, 28 to 88 years). Thirty-one patients (33%) were TAAA type I and 63 (67%) were type II. Aortic dissection occurred in 35 (37%) patients; rupture occurred in two (2%). Thirty-six patients (38%) had previously undergone proximal aortic surgery (11 elephant trunk procedures, 3 repairs of ascending aortic aneurysm, 2 ascending and transverse aortic arch aneurysms, 6 ascending aortic aneurysm and aortic valve replacements, 3 aortic valve replacements, 11 coronary artery bypasses). Associated diseases included high blood pressure in 72 patients (77%), chronic obstructive pulmonary disease in 23 (24%), renal insufficiency in 12 (13%), cerebral vascular disease in 11 (12%), coronary artery disease in 10 (11%), carcinoma in 6 (6%), aortic valve disease in 8 (9%), and vocal cord paralysis in 3 (3%). Fifty-five patients (59%) had aortic cross-clamp times of ≥45 minutes (range, 20 to 131 minutes).

The control group of 42 patients was for type I and type III TAAA repair between February 1991 and September 1992. Surgery was simple cross-clamp without the adjuncts of CSF drainage and DAP. This group included 22 male and 20 female patients. The median age was 68 years (range, 44 to 82 years). Twenty-four patients (57%) were type I and 18 (43%) were type II. Aortic dissection occurred in 13 (31%) and rupture in 4 (10%). Thirteen patients (31%) had previously undergone proximal aortic surgery. Eighteen (43%) had aortic cross-clamp times of ≥45 minutes (range, 14 to 103 minutes). Patients were evaluated after surgery by an independent neurologist. Those who were incapable of any movement whatsoever or who were capable of some movement if free of gravity were classified as having paraplegia; those who were capable of motion against gravity and able to stand or walk with assistance were classified as having paraparesis. A patient was defined as having early neurologic complications if symptoms were evident on awakening, and as having delayed neurologic deficit when awakening neurologically intact and moving all extremities but subsequently having paraparesis or paraplegia. In the analysis of the success or failure of CSF drainage and DAP, we considered all neurologic deficits to be equal and indicative of failure of the method of protection regardless of the severity.

Passive moderate hypothermia, in which rectal temperature was permitted to drift to approximately 34° to 32° C, was used with CSF drainage and DAP in 36 of 94 patients (38%). Of these 36 patients, 14 were TAAA type I and 22 were type II. Twenty-two (61%) had aortic cross-clamp >45 minutes. Neurologic deficits developed in three patients (12%).

Patients were rewarmed at the end of aortic repair using a heat exchanger and BioMedicus pump (BioMedicus, Minneapolis, Minn.).

Statistical methods. Pearson's χ^2 test was used for simple univariate significance testing. Multivariate logistic regression analysis was used to adjust for potential confounding factors. Adjusted odds ratios and their confidence intervals were computed from the multivariate logistic regression models.

Technique (CSF drainage and DAP). Because these techniques are well described in our previous article,[4] we present here a brief outline of operative techniques. After anesthesia was induced, the patient was placed in a lateral position, and a 14-gauge Touhy needle was inserted in the intervertebral space between L3 and L4. The patient was placed in the thoracoabdominal position, and the thoracoabdominal incision was made. The left atrium was cannulated; if difficulty was encountered, the superior or inferior pulmonary vein was cannulated. The left femoral artery was cannulated, or, in cases of occlusion or previous aortobifemoral bypass surgery, the distal thoracic or proximal abdominal aorta was used as the point of inflow.

The aorta was cross-clamped sequentially beginning either proximal or distal to the left subclavian aorta and again at the middle portion of the descending thoracic aorta. The proximal aorta was transected and the graft anastomosed. The clamp was moved down and placed at the infrarenal abdominal aorta, and the remainder of the aneurysm was opened. The celiac axis, superior mesenteric, and both renal arteries were perfused through a multiple-port perfusion catheter. (This catheter, previously illustrated,[4] is constructed on-site and is not commercially available at present.) Patent intercostal arteries from T8 to T12 were anastomosed to the graft except in cases of aortic dissection or severe atheromatous plaque that could cause leakage at the suture site. The celiac axis, superior mesenteric, and both renal arteries were anastomosed. Antegrade flow was started, and the distal anastomosis was completed. During the completion of the anastomosis of the distal aorta, the patient was rewarmed to a rectal temperature of 37° C. The CSF drainage catheter was left in place, and CSF pressure was monitored continuously for 3 days after surgery. CSF pressure was maintained at ≤ 10 mm Hg.

RESULTS

All patients survived surgery. The overall 30-day mortality rate was 10% (9 of 94 patients). Causes of early postoperative death were multiorgan failure in four patients and cardiac arrest in five. Five patients (5%) had early neurologic deficit. Three patients (3%) had delayed neurologic deficit. Early pulmonary complications occurred in 39 patients (41%), cardiac complications in 17 (18%), bleeding in 10 (11%), renal insufficiency in 20 (21%), strokes in 2 (2%), vocal cord paralysis in 8 (9%), sepsis in 5 (5%), and coagulopathy in 7 (7%).

Intraoperative data. Intercostal arteries T8 through T12 were reattached in 65 patients (69%). Median CSF drainage was 45 ml during surgery (range, 5 to 684 ml) and 94 ml after surgery (range, 0 to 804 ml). Median pump DAP flow was 1.3 L/min (range, 0.1 to 6.5 L/min). Median total aortic clamp time was 48 minutes (range, 20 to 131 minutes). Visceral and renal ischemic time was 22 minutes (range, 3 to 60 minutes). Median pump time was 48 minutes (range, 12 to 113 minutes). Urine clearance time or the time until the appearance of indigo carmine in the urine was 12 minutes (range, 2 to 83 minutes).

Comparison results. We compared the neurologic complications of our current group of 94 patients with the data of 42 patients who also underwent repair of TAAA type I and type II with only simple cross-clamp. Both groups were treated by the senior author (HJS) at the same institution. Total neurologic complications for the current group occurred in 8 of 94 patients (9%) versus 8 of 42 (19%) for the control group ($p = 0.090$). Neurologic complications for type I occurred in 0 of 31 (0%) versus 1 of 24 (4%) ($p = 0.45$). Neurologic complications for patients with type II TAAA occurred in 8 of 63 (13%) versus 17 of 42 (41%) ($p = 0.014$). For all patients with aortic clamp times ≥ 45 minutes, neurologic complications occurred in 7 of 55 (13%) versus 7 of 18 (39%) ($p = 0.033$).

Table I shows four separate statistical models. Model 1 gives the effect of adjuncts alone, (CSF drainage plus DAP vs aortic cross clamp) and is unadjusted for any factors; model 2 gives the effect of adjuncts adjusted for extent; model 3 gives the effect of adjuncts adjusted for aortic clamp time; and model 4 gives the effect of adjuncts adjusted for extent and aortic clamp time. The fourth model was considered the best model. Three factors—adjunct, extent, and aortic clamp time—are significant. Results are essentially unchanged when the variables of age, sex, dissection, hypertension, and previous surgery were included in the model. Statistical interactions between adjunct and extent and adjunct and clamp time were not statistically significant. Models 3 and 4 are illustrated graphically (Figs. 1 through 3) by plotting

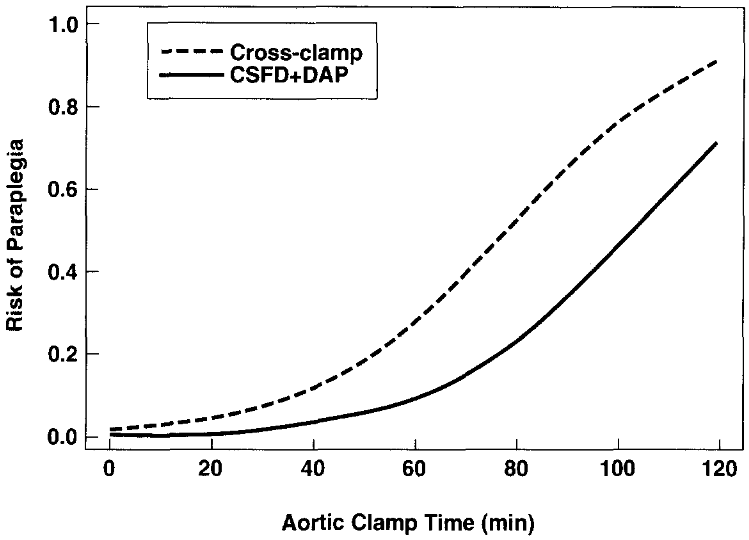

Fig. 1. Risk versus clamp time by treatment.

Table I. Multiple logistic regression analysis

Model	*OR*	*CI*	*p*
1. Adjunct*	0.40	(0.14, 1.15)	0.090
2. Adjunct	0.21	(0.06, 0.68)	0.0053
+			
Extent (II vs I)	19.9	(2.34, 169)	0.0033
3. Adjunct	0.26	(0.08, 0.86)	0.023
+			
ACT (↑ 15″)†	2.27	(1.48, 3.50)	0.0002
4. Adjunct	0.20	(0.06, 0.69)	0.010
+			
Extent (II vs I)	7.34	(0.75, 72.3)	0.081
+			
ACT (↑ 15″)	1.84	(1.12, 3.02)	0.015

OR, Odds ratio; *CI*, confidence interval.
*Adjunct: CSFD and DAP vs aortic cross clamp.
†ACT: aortic clamp time, relative risk for 15 minutes.

the expected risk of paraplegia versus aortic clamp time separately for each treatment. The risks are higher in the cross-clamp group, and this difference is more pronounced for type II. In Fig. 1 the curves are separated by 25 minutes, which indicates that the adjunct of CSF drainage and DAP essentially adds 25 minutes for the same level of risk.

DISCUSSION

The current study shows that CSF drainage and DAP in the repair of TAAA types I and II have a great impact on lowering the incidence of neurologic complications. To avoid the possible confusion related to lumping analyses of all types of TAAA together and to clearly understand the variations and the success rates in applying an adjunct in the prevention of neurologic complications, we examined the outcome of only those patients at highest risk, or TAAA types I and II.[4] In previous reports the incidence of paraplegia and paraparesis for patients with TAAA type II has ranged from 28% to 31%, but in our experience we found that CSF drainage and DAP can lower this rate to 9%.[4,5,16] The rationale behind the use of CSF drainage and DAP in the treatment of TAAA is the ability of these adjuncts to increase the tolerance of the spinal cord to ischemia by increasing spinal cord perfusion and thus allowing enough time to perform the surgical repair of TAAA, including the reimplantation of intercostal arteries T8 to L2. DAP during aortic cross-clamping has a salutary effect on the hemodynamic changes of the heart during both application and removal of the clamp and thus prevents wide and fluctuating blood pressure of the patient. Adequate DAP is assured by

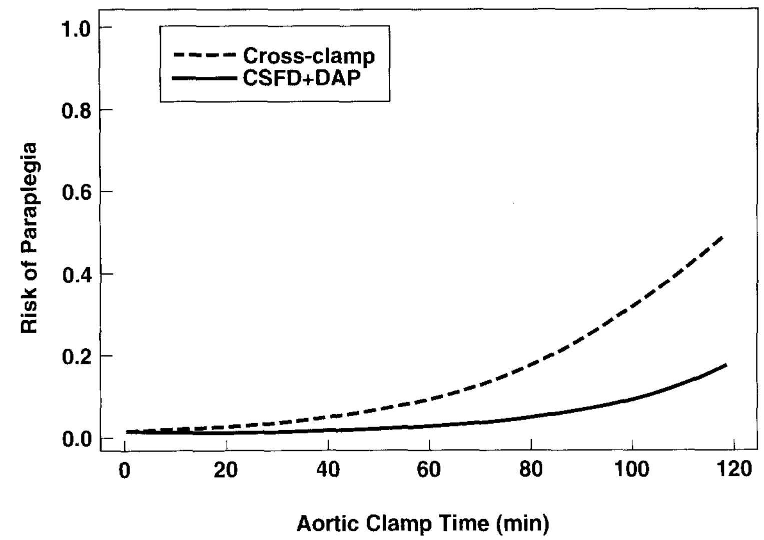

Fig. 2. Risk versus clamp time by treatment—extent I.

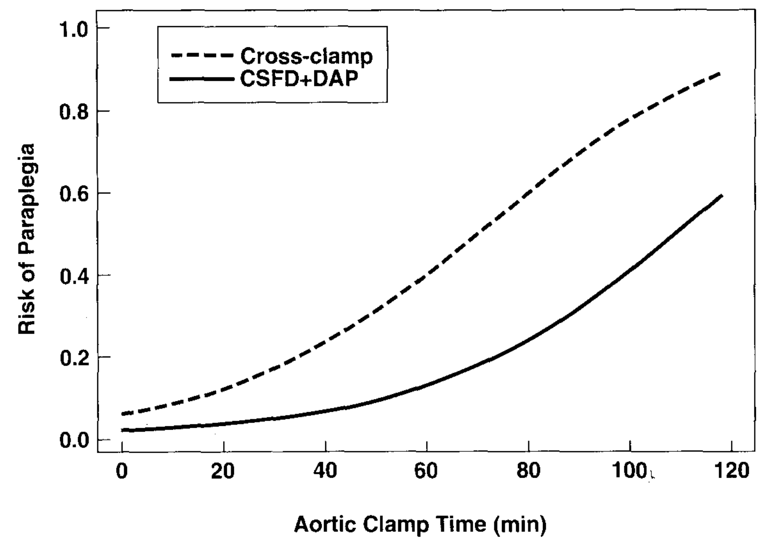

Fig. 3. Risk versus clamp time by treatment—extent II.

sufficient urine output and by maintaining good proximal aortic pressure (> 100 mm Hg) to prevent the deleterious effect of proximal arterial hypotensive pressure.[4,10,15,17]

In conjunction with CSF drainage and DAP, the sequential cross-clamping of the aorta is of paramount importance. While the aorta is cross-clamped proximal or distal to the left subclavian artery and at the middle portion of the descending thoracic aorta, the visceral and intercostal arteries are perfused to prevent ischemia to the viscera while the proximal anastomosis is completed. As reported previously, visceral ischemic time > 45 minutes is associated with an increased incidence of paraplegia and other complications such as multisystem organ failure.[5,16,18] Use of visceral perfusion may protect the liver and intestines for prolonged periods of aortic cross-clamping and prevent subsequent deleterious effects on coagulation or neurologic complication.

Intercostal arteries were reimplanted in 69% of the patients in this study, and we strongly believe that intercostal artery reimplantation, especially of arteries T8 through L2, is important because it has been shown in animal and human studies that the artery of Adamkiewicz originates from this segment of the aorta in 85% of cases.[4,5,19] As shown previously, intercostal artery reimplantation was inseparable as a risk factor with aortic clamp time, especially in cases of TAAA type II.[5] The difficulty in interpreting these methods of reimplantation of intercostal arteries, however, is that only 50% of the reimplanted arteries are patent, as demonstrated in postoperative aortography.[5,14,20,21]

A further advantage of the pump is the attachment of a heat exchanger that permits us to raise patient temperature at the end of the procedure from the passive hypothermic temperature of 34° to 32° C. The lowered body temperature may have a salutary effect on the spinal cord by lowering metabolic needs and further increasing spinal cord tolerance to ischemia. Thirty-six of 94 patients (38%) received passive hypothermia in the current study, the genuine effects of which will have to be examined in a future series.

Thus far, with CSF drainage and DAP, neither early or late paraplegia had developed in patients with type I TAAA. Should this trend continue, we may be able to focus our future concerns on type II alone.

This study clearly points to the great impact of CSF drainage and DAP in extending the tolerance of the spinal cord to ischemia and in decreasing the incidence of neurologic complications, especially for patients with TAAA type II.

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DISCUSSION

Dr. Charles W. Acher (Madison, Wis.). The results of this report are essentially identical to the authors' first report using this technique, and document a 9% incidence of paralysis in a combined group of 94 patients with Crawford type 1 and type 2 aneurysms. As a retrospective control group, the authors used 42 patients treated by the standard Crawford technique. The authors exclude from comparative analysis 36 patients with type 1 or 2 aneurysms who had DAP alone, 2 patients with CSF drainage alone, and 52 patients with type 3 and 4 aneurysms.

To add some objectivity to analysis of paralysis risk in a clinical series, in 1993, we presented a mathematical model of paraplegia risk based on extent of aortic replacement and clinical presentation, which accounted for more than 95% of the variability and paralysis rate between 17 clinical series published up to that time. This model predicts 10 deficits for Dr. Safi's control group of 42 patients – there were 8 actual deficits – and it predicts 10 deficits for the 38 excluded patients, 36 of whom had DAP. The adjunctive treatment group had 25 predicted deficits, but there were only 8 deficits, a two-thirds reduction in the expected number of paralyzed patients in this adjunctive group. This model analysis of Dr. Safi's data confirms prospectively that paralysis rates with DAP or aortic occlusion alone are predictable and the same.

If we add Dr. Safi's data to 26 other series published up to 1995 and do a model analysis of this very large accumulated experience, we see a very interesting thing. Series with CSF drainage and one other adjunct have a paralysis rate of approximately one third that of DAP or cross-clamping alone. This group analysis parallels Dr.Safi's experience, but more importantly, points in a direction that is perhaps fruitful and real for reduction of paralysis incidence in these patients.

Other exciting clinical experiments are occurring today: epidural cooling, segmental intercostal cooling, the parallel experiences of Drs. Frank and Williams in Baltimore, the reemergence of hypothermic circulatory arrest with improved morbidity, and our own continued positive experience with CSF drainage and multifactor control. But we will lose the possible benefit from these embryonic experiments unless we understand them in context and study what they do and do not teach us.

Dr. Safi, you only withdrew a mean of 45 ml of CSF during the procedure to keep the CSF pressure below 15 mm Hg. Most groups that do CSF drainage would remove more fluid to keep the pressure lower. Why not control CSF pressure at a lower level than you do?

You did not reimplant intercostal arteries in patients with dissection, which I agree is reasonable, even though dissection patients notoriously have more intercostal arteries open than other patients. These dissection patients had an equal or lower paralysis rate than your other patients; therefore, what is your rationale for continuing to reimplant intercostal arteries? Did you model dissection alone to see its impact, i.e., intercostal artery reimplantation?

Dr. Hazim J. Safi. To answer your first question about CSF drainage, only in our first study of 45 patients did we keep CSF pressure at 15 mm Hg. This was so we could compare our results with the previously published results of the historic group. Since then, we keep the CSF pressure at 10 mm Hg or less both during surgery and up to 3 days afterward.

To answer your second question about reimplanting intercostal arteries, I reimplanted all intercostal arteries except in two conditions – that of acute aortic dissection or the presence of calcified atheromatous plaque of the aorta. I do not recommend endarterectomy because of the hazard of postoperative bleeding and possible fatal outcome.

If we exclude patients in whom I ligated the intercostal arteries and the patient whose postoperative bleeding caused severe hypotension, none of our patients developed paraplegia. None of our type I TAAA patients had neurologic complications, and I think that if this favorable trend continues, we will no longer include them in studies specifically concerning high-risk patients. By the way, I do not differentiate between paraplegia or paraparesis. Any neurologic deficit is a failure of the method of protecting the spinal cord during aortic aneurysm repair.

Dr. Richard P. Cambria (Boston, Mass.). Based on your technique, it would appear that the period of protection for those critical intercostal vessels with retrograde perfusion is limited to the time required to perform the proximal anastomosis. In my own experience, a minimum amount of the total aorta cross-clamp is expended for performance of the proximal anastomosis. How much time are we really buying with DAP for perfusion of those critical intercostals in the T8 to L1 level?

Dr. Safi. The idea behind sequential clamping with CSF drainage and the pump was to extend the tolerance of the spinal cord to ischemia. I think we are buying about 10 to 15 minutes to do the proximal anastomosis during that time while the visceral, renal, and intercostal arteries are perfused. However, our study was focused on CSF drainage and DAP extending the tolerance of the spinal cord to ischemia, irrespectively of perfusion of the intercostal arteries.